Adaptive Air Transportation System – A Catalyst for Change

John Zuk[*], Robert K. Callaway, and Douglas A. Wardwell[**]

NASA Ames Research Center

Moffett Field, California

Abstract

As the air transportation system capacity approaches saturation, the option of providing additional conventional runways becomes prohibitively expensive and politically charged. The technologies and capabilities exists that would enable over 40 % of the total aircraft operations be diverted to underutilized infrastructure.

In order to get a potentially large increase in capacity, it can be reasoned that one needs to look at the global transportation system from a system-wide level and address the relationship of operations, economics, and vehicles. Numerous solutions have been proposed to increase the capacity and mobility of the air transportation system. However, none of these approaches appears to have the potential to solve the Nation's future airport capacity and mobility issues. A possible solution might be a modification and expansion to the current system that allows a new class of vehicles to be operated, and along with it, a new way of operations that is different than the current system. Numerous technology advancements, such as computing power, avionics, intelligent flight controls, high bandwidth data transmissions, and powered-lift concepts can be a catalyst to develop an adaptive air transportation system to solve the future need.

The Problem

Aviation system delays are projected to increase, creating a severe drag on economic growth in coming years. Without improvements, the economic cost of delays between 2000 and 2012 (including the denial of access) could approach an estimated $170 billion.[1] Even if the FAA's Operational Evolution Plan (OEP) invests the planned $1 billion annually over the next 10 years, it may be insufficient for meeting the total demand for air transportation. Does this mean that some people will be forced to use other means of transportation? No, it does not.

Making the assumption that a growth constrained air transportation system is not acceptable suggests the evolution to an Adaptive Air Transportation System (AATS). This system would allow the air transportation system (ATS) to continuously evolve into a more efficient system. In the future, aircraft and airports would adapt to the particular demands of the environment that will greatly increase the current capacity and enhance the accessibility of air travel.

Background

The number of delayed flights in the National Airspace System has more than doubled in the 6 years prior to 2002 (Fig. 1).[2] Due to environmental issues and cost, only one major new U. S. airport, Denver International, was opened during the past decade. With little ability to build new airports or expand current airports serving populated areas where they are needed, it is now recognized that the capacity of the nation's air transportation system will not meet consumer demand. The number of airport delays will continue to increase, and the nation's economy and mobility will be adversely impacted[3].

---

[*] Member, AIAA
[**] Associate Fellow, AIAA

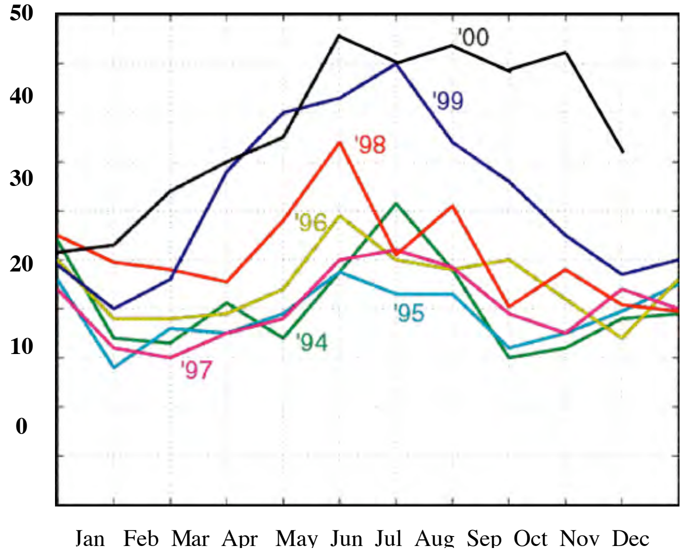

Figure 1. The total U.S. ATC system delays (thousands of flights with delay >15 min.).[2]

A study prepared by DRI•WEFA, Inc. and the Campbell-Hill Aviation Group[1] found that without aggressively addressing the airport delay problem, these delays would have considerable impact on the U.S. economy. The study concluded that in 2000 aviation contributed to nine percent of the nation's gross domestic product and was responsible for 11.2 million jobs. It also reports that air passengers and the shipment of air cargo could be spared delays of nearly 64 million hours per year if the government pursued early completion of runway and airway infrastructure

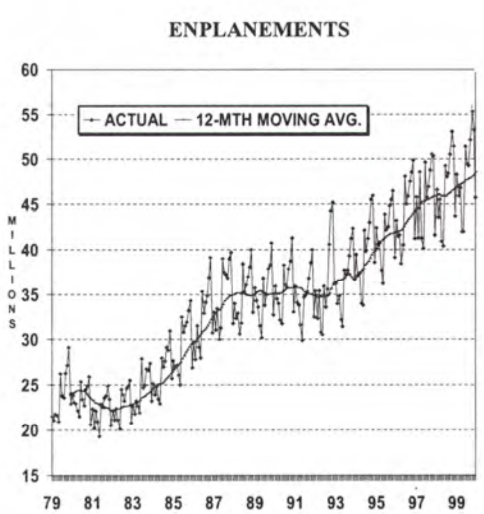

Figure 2. Monthly Passenger Enplanements.[3]

improvements over the next ten years. U.S. air traffic system delays in 2000, as measured by the FAA, cost the U.S. economy $9.4 billion.

In 2001, the FAA forecasted that U.S. air travel demand would increase from 660 million enplanements in 1999 to 1.05 billion in 2011[3]. By 2004, the FAA and others forecast a return to a four- percent annual growth rate, or doubling every 18 years. Figure 2 shows a historical record of monthly passenger enplanements from 1979 to1999. This historical trend supports the increased growth rate forecast. Since US airline deregulation in 1979, airline passenger demand has grown faster than the population and economic growth rates such as the National Gross Domestic Product.

Even the setback, caused by the event of September 11, 2001 appears to be temporary as traffic volume, which initially dropped by as much as 30 percent, is now within 10 percent of the demand prior to 9/11. Note previous cataclysmic events and recessions only delayed the growth curve (see Fig. 2).

Infusion of Technologies

As the air transportation system capacity approaches saturation, the option of providing additional conventional runways becomes prohibitively expensive and politically charged. Conversely, computing power, avionics, high bandwidth data transmissions, and intelligent flight control capabilities have expanded many-fold while their relative costs have decreased. Satellite-based navigation, communication, and surveillance provide far better flight path flexibility and accuracy than the predecessor ground-based systems and without the costly infrastructure. These technologies along with the excellent low speed performance characteristics of powered-lift vehicles could help the evolution of the ATS.

What lessons can we learn by studying lessons learned in other industries that have tried to bring in new technologies and those from

NASA's history with infusing technologies into the ATS?

Electric Vehicles

In 1990, the California Air Resource Board (CARB) promoted Electric Vehicles (EV) by mandating that by 1998, 2 percent of automobiles sold in California had to have zero tail-pipe emissions. Currently if you look on the CARB website under Zero Emission Vehicles you will find vehicles on this site that are called Hybrid Electric Vehicles (HEV). One of the things that make these vehicles unique is that they are not zero emission vehicles! Why are these HEV's listed here and what lesson can we learn from this that could be applied to air transportation?

Currently the CARB requires 10 percent of automobiles sold by 2003 be zero emission vehicles, with allowances given for HEVs. Though this mandate did prompt the automotive industry to develop technically acceptable EV's, this technology insertion was unsuccessful for a variety of reasons.

One reason was that they tried to insert this type of technology without the proper infrastructure to support it. This was also further complicated by the consumer impression that they would have to alter their driving habits (operational methods) to successfully operate electrical vehicles. Some of the habits that might need to be changed were the length of trip, speed of trip, overnight storage of vehicle, etc. Though not any one of these was "the reason" why consumers did not flock to these types of vehicles, it was a feeling that they needed to make a great change in their habit patterns.

Hybrid Electric Vehicles

Although Hybrid Electric Vehicles (HEV) did not fall under the original mandate, it became apparent that this type of vehicle could be path on which the ultimate goal of zero emissions could be met. A vehicle is considered a hybrid if it combines two or more sources of power. The internal combustion-electric car is a cross between a gasoline-powered car and an electric car. The significant operational difference between the HEV and the EV is that the HEV uses the existing infrastructure and allows the operator to generally maintain their operational methods.[4]

Short Haul Civil Tiltrotor

The XV-15 tiltrotor experimental aircraft successfully demonstrated (1979) the capabilities of an aircraft that could operate in both the vertical and extremely short takeoff and landing modes and still have good cruise speeds and range. The XV-15 not only gave rise to the V-22 Osprey, but it also led to the possibility of tiltrotor commercial passenger service. In 1994 NASA instituted an eight-year Short Haul Civil Tiltrotor (SHCT) program. The SHCT goals were to overcome the technology barriers that inhibited a tiltrotor from being inserted into the National Airspace System (NAS). Another finding from this program was the verification that powered-lift rolling takeoffs and landings result in lower pilot workload and more efficient operations than vertical flight operations.

The 1995 National Civil Tiltrotor Development Advisory Committee (CTRDAC) report[5,6] concluded that the civil tiltrotor could significantly reduce travel delay, was technically feasible, and could be economically viable under certain circumstances.

Although the SHCT program met all its goals[7], why are there not SHCT's in the NAS today? What NASA discovered was that the inclusion of a civil tiltrotor was inhibited more by the lack of infrastructure than by the lack of a technology. Basically, the vertiport infrastructure would not be developed without a vehicle and vise versa. Development a new transportation vehicle while simultaneously developing the infrastructure that supports that vehicle appears, as history has shown us, not to be a practical approach.

The lessons learned from the SHCT program and EVs has led us to the conclusion that to

Figure 3. Public runways available in the United States.

insert new technology into a transportation system, such as NAS, it has much a better chance of acceptance and success if it can use parts of the existing infrastructure.

Solutions

Numerous solutions have been proposed to increase the capacity and mobility of the air transportation system. One of the recent efforts includes the introduction of very large aircraft, such as the Airbus A380 now under development, to serve high-density international routes and more point-to-point service. There is also the Boeing proposed Sonic Cruiser—a high subsonic Mach Number aircraft that would reduce trip time, especially on long-haul trips. Any solution that is proposed to the global transportation system must be evaluated from a system-wide level.

NASA is also working to increase the capacity of the NAS. Some NASA programs that have addressed, or are addressing, these issues are the SHCT, the Aviation Capacity System (ASC), the Small Aircraft Transportation System (SATS), and the Aviation System Technology Advanced Research (AvSTAR) Programs. The SATS program addresses general aviation and new related technologies. The ASC/AvSTAR programs are working on solutions to optimize and enhance the current NAS system. However, none of these approaches appears to have the potential to solve the Nation’s airport capacity and mobility issues and meet the long-term growth projections.

As previously discussed, the current system will, at some point in the near future, reach its capacity. Therefore something must be changed in order for the system to overcome this limitation. These limitations appear to be caused by, but not limited to, the following:

- Limited amount of tarmac/runways.

- Limited amount of airspace over current hubs.
- FAA legacy system procedures—developed from radio beacon technology of the early 50's—limits what can be done operationally, especially with the recent advances in satellite-based technology.
- The metric of $/seat-mile per aircraft does not show the overall benefit/profit of the system as a whole.

An additional observation was that, typically, commuter (i.e. short-range) aircraft at large and medium hub airports comprise 40 % of the total aircraft operations, but are only responsible for carrying 20% of the passengers. These commuter routes are less than 500 nautical miles, but the commuter aircraft serving these routes typically use the primary runways used by the long-range jet transports.[8] NASA's SATS program, as well as other studies, have shown that even though there is some scheduled service to about 850 airports in the U.S., there are more than 5,000 airports with paved runways 3000 feet or longer. Figure 3 shows the number of public runways available in the U.S. Could these short runways (including short runways at large airports) provide a partial solution to ATS capacity and mobility problem by providing additional runway and airspace?

An Adaptive System

A possible solution might be a modification and expansion to the current system that allows a new class of vehicles to be operated in a unique fashion that takes advantage of underutilized resources. As discussed earlier with the hybrid electric vehicles and the SHCT program, bringing in a new class of vehicles and a totally new infrastructure appears too prohibitive from the manufacturer, operator, and customer standpoints.

In this future adaptive system, aircraft and airports would adapt to the particular demands of the environment. These constraints could be physical, political, environmental, air traffic density, or meteorological conditions. This type of system/vehicle will have to judged on its overall benefits to the NAS/U.S. economy, not solely on $/seat-mile/aircraft.

One way to increase the efficiency of the ATS is to use the underutilized part, or parts, of the system, such as the available short runways, small airports, and associated airspace (Fig. 4). This can be achieved by developing new procedures that take advantage of the maneuver characteristics of a broad spectrum of powered-lift aircraft. For the purpose of this paper, powered-lift vehicles (PLV's) are defined as a class of aircraft that can: (1) operate IFR to short runways (typically ≤ 3000 feet); (2) use approach and departure corridors separate from current subsonic transports; and (3) if needed, can also operate under the same NAS rules as current subsonic transports.

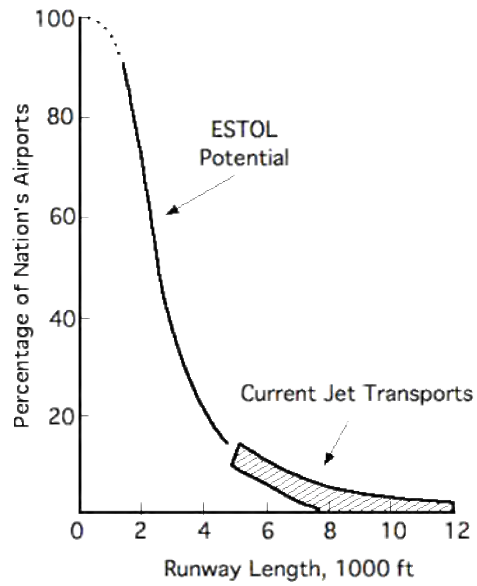

Figure 4. Potential airport utilization.

Operations

The unique flight characteristics of powered-lift aircraft enables the use of a curving approach (or departure) under both VFR and IFR permitting disparate aircraft operation in IMC conditions using simultaneous non-interfering adverse weather (SNI-AW).[9]

For example, an arriving powered-lift aircraft would come in high and fast and then make a descending-decelerating-turning approach to land—this type of approach is quickest method to land vehicles. With this type of procedure, a

Figure 5. A proposed powered-lift aircraft flying SNI-AW curved approach and departure patterns.

Powered-Lift aircraft could make simultaneous non-interfering approaches with conventional takeoff and landing (CTOL) aircraft (Fig. 5).

Utilizing short runways, either at small airports or at major hub airports, could greatly increase the capacity and mobility of the ATS under both VMC and IMC conditions. Today, the global positioning satellite (GPS) system offers the potential to easily enable SNI-AW approaches. The implementation of the wide area augmentation system (WAAS), the local area augmentation system (LAAS), and automatic dependent surveillance-broadcasting (ADS-B) the will further enhance this capability. These new systems, along with the small turning radius enabled by a powered-lift vehicle's slow approach and landing speeds, will potentially allow new operating procedures that would keep its noise footprint contained within an airport boundary. Additionally, numerous other technology advances such as avionics, computing power, and high bandwidth data transmission will contribute to making these procedures practical.

Powered-lift SNI-AW operations also have the potential to reduce delay and increase capacity (access) in constrained terminal airspace by taking current aircraft out of the CTOL system, while at the same time using underutilized space at various airports. Logistics Management Institute has conducted a NASA sponsored study, which identified underutilized space at major airports.[10] Using its Future Flight Central Facility, NASA Ames has demonstrated this potential by utilizing the cargo area at Dallas Fort Worth Airport for powered-lift SNI-AW operations.

Powered-Lift Vehicles

With the advanced avionics and intelligent flight controls, PLV's, characterized by excellent low speed performance and control capabilities, have the potential to achieving a full spectrum of operations under IMC. With their low takeoff, approach, and landing speeds, they can also greatly reduce the space requirements for their primary takeoff and landing surfaces and overrun margins. Additionally, the lower terminal area speeds of these aircraft reduce turn radii in terminal area patterns. Their low speed performance may also be used for steeper approach and departure angles while maintaining constant rate of descent or climb. The tight turn and steep flight path angle trajectories enabled by the PLV's provide the opportunity to weave approach and departure streams around the conventional aircraft traffic streams--adding to airport capacity.

Much of the technology proposed for this is basically available today. However, a focused effort is needed to identify the optimum combination of technologies that yields an economically viable vehicle from a system-wide standpoint. Over the years, many powered-lift transport type vehicles have been flown and tested; some of which are shown in figure 6. Some of the concepts explored for short takeoff and landing capability included internally blown flaps, externally blown flaps (EBF), upper surface blown flaps (USBF), deflected slipstream, tilt-wing, and tiltrotor technologies. Comparisons for the performance for the first 5 of these have been updated and presented by Margason.[11]

(a) C-17 Globemaster III—uses EBF technology.

(b) NASA Quiet Short Haul Research Aircraft (QSRA)—uses USBF technology.

(c) YC-15—uses EBF technology.

(d) YC-14—uses USBF technology.

(e) NASA C-8A Buffalo Augmentor Wing Jet-STOL research aircraft.

(f) Russian AN-74—uses USBF technology.

Figure 6. Various transport-type powered-lift concepts.

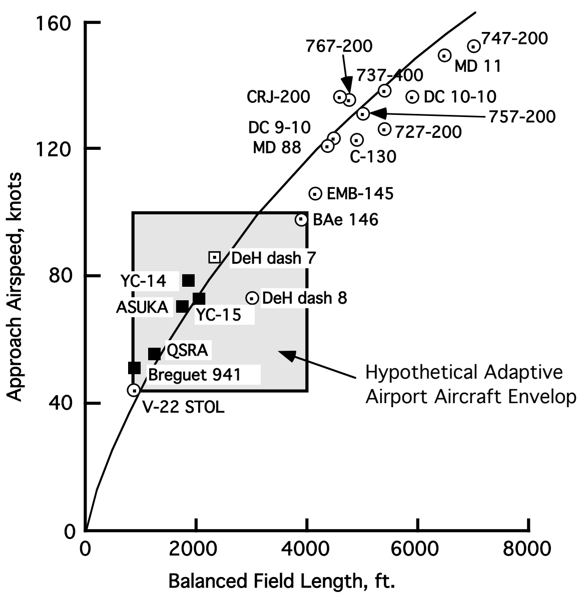

Figure 7. Comparison of vehicle landing performance.

A comparison of approach speed versus landing field length is presented in 6. It is envisioned that a powered-lift solution envelop exists that is somewhere between the performance of a tiltrotor on the very low landing field length end and to that of a BAe 146 (or Avro RJ) class of aircraft (Fig. 7).

NASA Ames Research Center, in conjunction with Cal Poly—San Luis Obispo, and Boeing Phantom works, Long Beach has proposed a notional powered-lift vehicle that provides nominal PLV performance at very low risk (i.e. no major technology development required).

For this vehicle, Ames challenged the Cal Poly Aero Design Team the problem to mate a scaled C-17 class externally blown flap wing with a BAe 146-100 fuselage. Requirements were for the vehicle to have a range of 1,000 nmi, hold 70 passengers, and have a 2,000 ft. balance field length.[12]

What resulted was a notional powered-lift vehicle in the 78,000 lb TOGW class that could meet the 2,000 ft balance field length with one engine out, had an approach speed of approximately 75 knots, and had a landing speed of approximately 68 knots (Fig. 8).

Figure 8. Notional 70-100 passenger powered-lift commercial vehicle.

As previously discussed there is a vast amount of unused runways in the U.S. that could be used. A study conducted for NASA Ames by the Cal Poly design team[12], found 50 available runways (excluding those that can land large aircraft) in California that meet the following requirements:

- Daily commercial flights
- Existence of Control Tower
- Runway size (3000-6000 ft.)
- Ramp weight, that would allow 78,000 lb TOGW

The results are presented in figure 9. This provided insight into the possibility that it appears to be more feasible to build smaller PLV's and utilize the available runways nearer to the public than to expand a select few large airports farther from the public for larger aircraft ("bring the airport to the passengers").

The design, operation, and economic issues involved with the operation of this proposed class of new vehicles into the ATS need to be addressed in detail. Some of the items that will need to be evaluated are:

Figure 9. California airports that are 3,000 to 6,000 ft. with at least a 78,000 lb. ramp weight.

- Procedures for optimizing airport efficiency and minimizing the environmental impact (noise, new runways, etc.) at small airports.
- Optimum vehicle characteristics such as range, number of passengers, cruise speed, landing & takeoff distance, etc.
- Procedures optimizing airport efficiency and minimizing the environmental impact (noise, new runways, moving smaller vehicles to smaller/underutilized runways, etc.) at major hub airports.
- Cost of operations and development.

Conclusion

In order to get a potentially large increase in capacity, it can be reasoned that one needs to look at the global transportation system from a system-wide level and address the relationship of operations, economics, and vehicles. The relationship of operations, economics, and vehicle designs must be better understood, so the solutions that become available are optimized system-wide.

A possible solution might be a modification and expansion to the current air transportation system that allows a new class of vehicles to be operated in a unique fashion that takes advantage of underutilized resources.

Merging advanced avionics and flight controls with the unique flight characteristics of powered-lift aircraft, enables the use of a curving approach (or departure) under both VFR and IFR, thus permitting disparate aircraft operation in IMC conditions using simultaneous non-interfering adverse weather (SNI-AW) approaches.

Most of these technologies are basically available today and could enable over 40% of the total aircraft operations to be diverted to underutilized infrastructure. However, a focused effort will be needed to identify the optimum combination of technologies that yields an economically viable vehicle from a system-wide standpoint.

In the future, aircraft and airports would adapt to the particular demands of the environment that will greatly increase the current capacity and enhance the accessibility of air travel.

References

1. Anonymous; “The National Economic Impact of Civil Aviation,” DRI•WEFA, Inc., July 2002.

2. FAA OPSNET ATO-200.

3. FAA Aerospace Forecast for 2000-2011.

4. Victor Wouk review of D. Kirsh book, “The Electric Vehicle and the Burden of History,” February 2001.

5. “Civil Tiltrotor Development Advisory Committee – Report to Congress,” U.S. Department of Transportation Federal Aviation Administration, Volume 1 – Final Report, Washington, DC 1995.

6. “Civil Tiltrotor Development Advisory Committee – Report to Congress,” U.S. Department of Transportation Federal Aviation Administration, Volume 2 – Technical Supplement, Washington, DC 1995.

7. “Airspace Systems Program PCA,” Version 1.0, February 28, 2002.

8. “Civil Tiltrotor Missions and Applications: The Commercial Passenger Market– Final Report,” NASA CR-177452, Boeing, Seattle, WA, February 1991.

9. "Rotorcraft Requirements in the Next Generation Air Traffic Management System," The Boeing Company, NASA Contract NAS 2-14116, Final Report, February 1998.

10. Johnson, J.; Stouffer, V.; Dou Long, Gribko, J.; "Evaluation of the National Throughput Benefits of the Civil Tilt Rotor;" Report NS003S1, Logistics Management Institute, McLean VA, January 2001.

11. Margason, R.J.; “STOL Aircraft Concepts for Runway Independent Application,” AIAA-2002-6025, 2002 International Powered Lift Conference, Williamsburg, VA., November 5-7, 2002.

12. NASA-Ames Cooperative Agreement No. 2-5508 with California Polytechnic State University Foundation, San Luis Obispo, August 1, 2002.